INFN High-Intensity Studies

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For the INFN Working Group

Proton Driver Workshop
Fermilab, 7 October 2004

Outline

- The INFN working group
- Physics cases
  - kaons
  - hadrons and QCD
  - muons
  - neutrinos
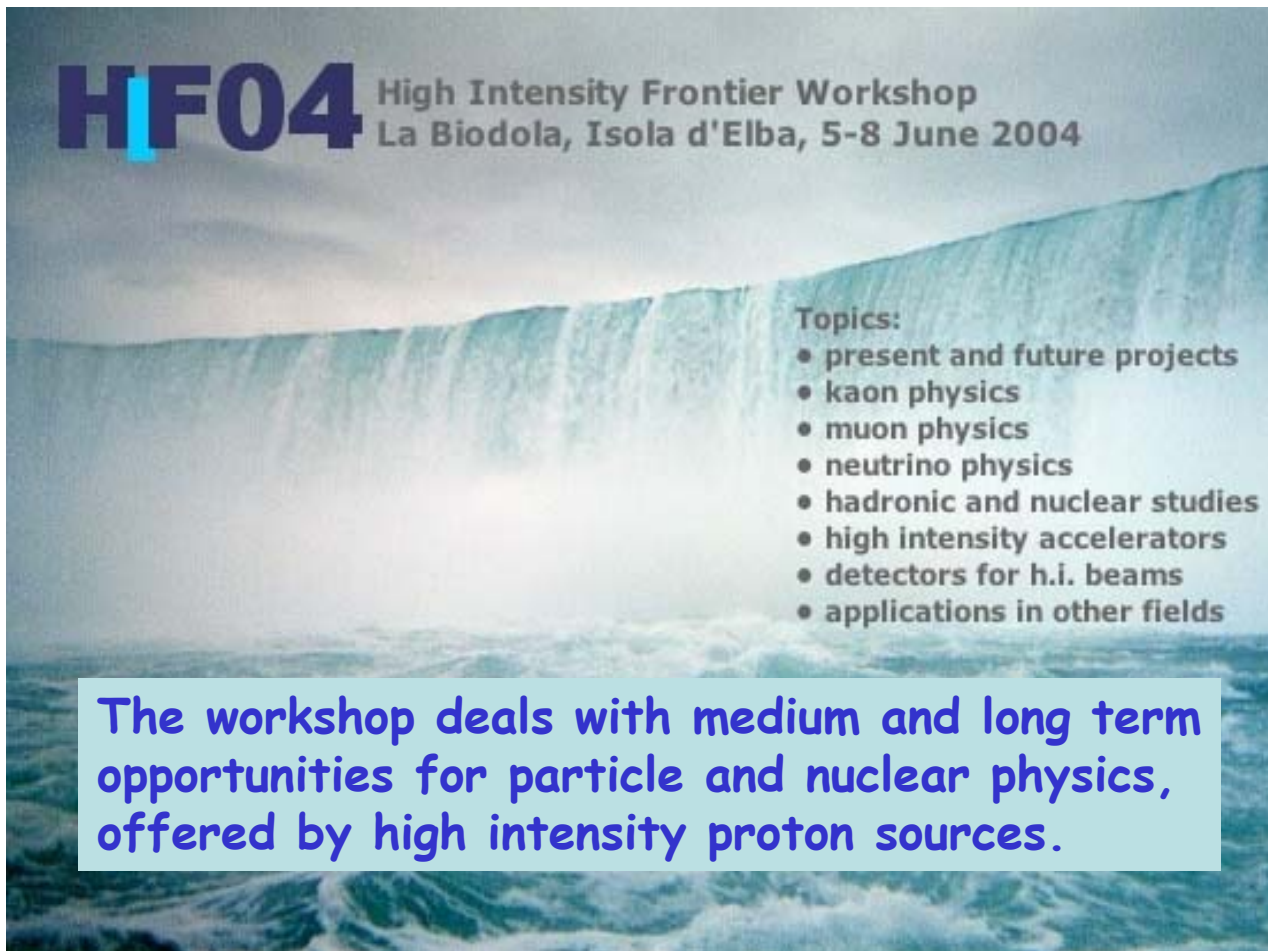- Outlook

The INFN Working Group - I

In early 2004 INFN established a working group (WG) to investigate physics opportunities in the LHC era. The WG addresses the following questions:

- What physics topics will need new experiments ?
  - Kaons, Muons, Hadrons, Neutrinos.
- How will these experiments be made ?
  - which accelerators ?
  - which detectors ?
- Where ?
  - In which lab should these experiments be carried out ?

In particular the Working Group was asked to investigate the physics opportunities offered by high intensity hadron beams available at:
  - Upgrades of existing machines
  - New machines

The INFN Working Group - II

HF04 High Intensity Frontier Workshop
La Biodola, Isola d'Elba, 5-8 June 2004

Topics:
- present and future projects
- kaon physics
- muon physics
- neutrino physics
- hadronic and nuclear studies
- high intensity accelerators
- detectors for h.i. beams
- applications in other fields

The workshop deals with medium and long term opportunities for particle and nuclear physics, offered by high intensity proton sources.

- HIF workshop at Elba (5-8/06)
- Contribution to the SPSC meeting at Villars (22-28/09)
- Contribution to the Fermilab Proton Driver Workshop (6-9/10).

Final aim: submit recommendations to INFN (white book)

Kaons

Why Study Rare Kaon Decays

- Search for explicit violation of Standard Model
  - Lepton Flavour Violation

- Probe the flavour sector of the Standard Model
  - FCNC

- Test fundamental symmetries
  - CP, CPT

- Study the strong interaction at low energies
  - Chiral Perturbation Theory, kaon structure.

- Good theoretical control.
- Provide Strong constraints on the CKM unitarity triangle independently from B measurements. Strong consistency check of CKM picture.
- K and B sectors are complementary for the precision study of flavour physics.

$K \to \pi \ell \, \bar{\ell}$

Phenomenological advantages well known

Experimental problems:
BR $\approx 10^{-11}$, few (or no) kinematic constraints, backgrounds with BR x 10^7

mode	SM prediction	Experiment	Comments
$K_L \to \pi^0 e^+ e^-$	$(3.7 \pm 1.0) \cdot 10^{-11}$ (CPV_{dir} 1-2 $\cdot 10^{-11}$)	< 2.8 $\cdot 10^{-10}$ (FNAL KTeV)	CPC+CPV, ee$\gamma\gamma$ bkg. 3 ev. (2.05 bkg)
$K_L \to \pi^0 \mu^+ \mu^-$	$(1.5 \pm 0.3) \cdot 10^{-11}$ (CPV_{dir} 1-5$\cdot 10^{-12}$)	< 3.8 $\cdot 10^{-10}$ (FNAL KTeV)	CPC+CPV 2 ev. (0.87 bkg)
$K^+ \to \pi^+ \nu \, \bar{\nu}$	$(8.0 \pm 1.0) \cdot 10^{-11}$ (at 7%). No CP	$1.47^{+1.30}_{-0.89} \cdot 10^{-10}$ (BNL E787+E949)	Dedicated expt. 3 evt. (bkg. 0.45)
$K_L \to \pi^0 \nu \, \bar{\nu}$	$(3.0 \pm 0.6) \cdot 10^{-11}$ (at 2%)	< 5.9 $\cdot 10^{-7}$ (KTeV, Dalitz decay)	Pure CPV dir "*Nothing to nothing*"

Dedicated experiments required

$K^0_L \to \pi^0 e^+ e^-$ and $K^0_L \to \pi^0 \mu^+ \mu^-$
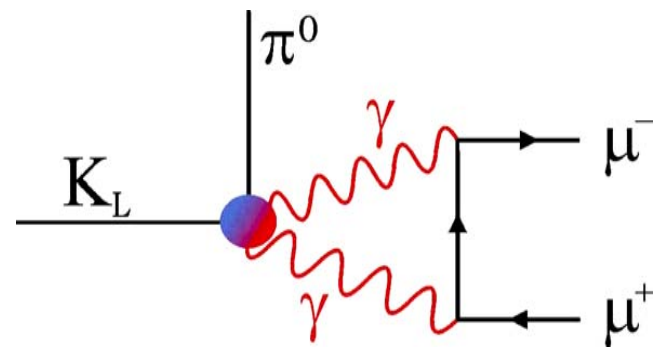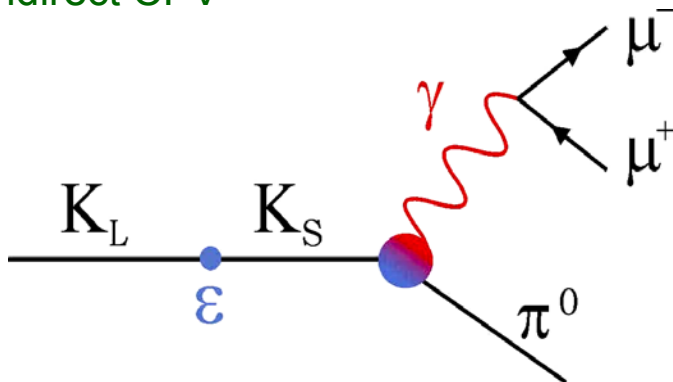
Study Direct CP-Violation

Direct CPV

- **Indirect CP-Violating Contribution has been measured (NA48/1)**
- **Constructive Interference (theory)**
- **CP-Conserving Contributions are negligible**
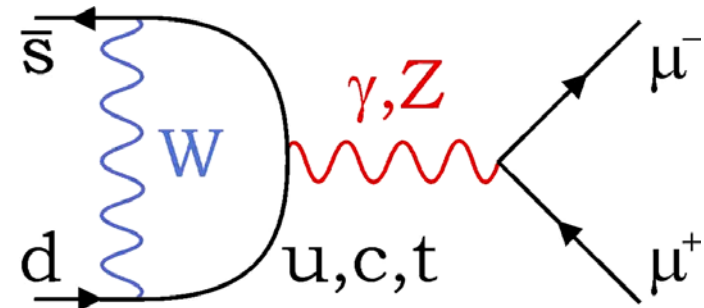
Indirect CPV

CPC

0^{++}, 2^{++}

$K^0_L \rightarrow \pi^0 ee\ (\mu\mu)$: Sensitivity to New Physics

Isidori, Unterdorfer, Smith:

$$Br(K_L \rightarrow \pi^0 \mu^+ \mu^-)\quad (\times 10^{-12})$$
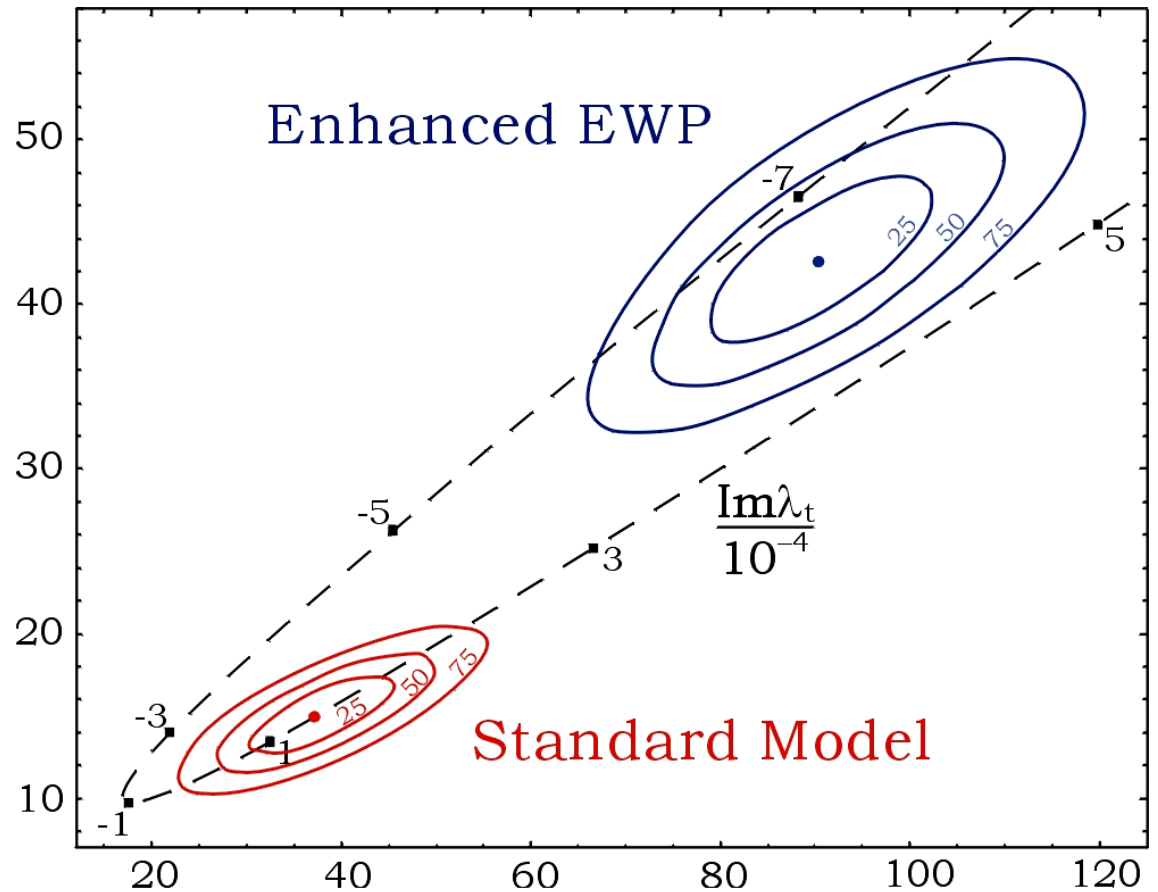
Fleisher et al:

Ratios of B → Kπ modes could be explained by enhanced electroweak penguins

and enhance the BR's:

$$B^{NP}_{e^+e^-} = 9.0^{+1.6}_{-1.6} \times 10^{-11}$$

$$B^{NP}_{\mu^+\mu^-} = 4.3^{+0.7}_{-0.7} \times 10^{-11}$$

* A. J. Buras, R. Fleischer, S. Recksiegel, F. Schwab, hep-ph/0402112

$K^+ \to \pi^+ \nu \bar{\nu}$

BR(SM) ~ 10^{-10} (3 events). Theoretical uncertainty ~ **7%** (going down to **2%** ?)

Background from K and beam: no kinematic constraints. Suppression 10^{11}: limited by physical processes. Redundancy, particle ID, kinematics, vacuum, live-time, VETO !!!

• Stopped K^+ approach has limits (stop fraction, slow PID, solid angle, π scatter, vetoing).

• In-flight approach (new): needs p_K measurement, no scattering, faster, better vetoing.
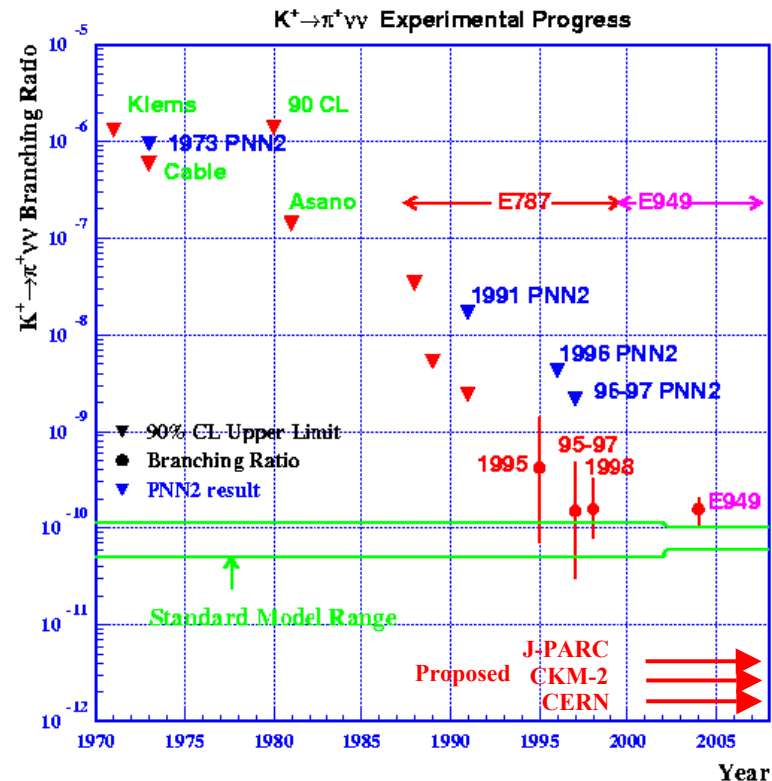
Will have some 10s of events

$K_L \rightarrow \pi^0 \nu \bar{\nu}$

"Direct" CP-violating
BR ~ $3 \cdot 10^{-11}$ (or NP?)
(limit $5.9 \cdot 10^{-7}$, bound $1.7 \cdot 10^{-9}$)
Theoretical uncertainty ~ **1-2%.**

Background from $\pi^0 \pi^0$.
$\gamma\gamma$ mode, n flux, hyperons, vacuum,
material, live-time.
Very few handles: missing p_T, VETO!!!

• KOPIO approach (40 events)
• KAMI-(KEK)-JPARC approach: large
acceptance, pencil beam (flux), rate!
(100-1000 events)
Several options (DC, energy, barrel
detection,...
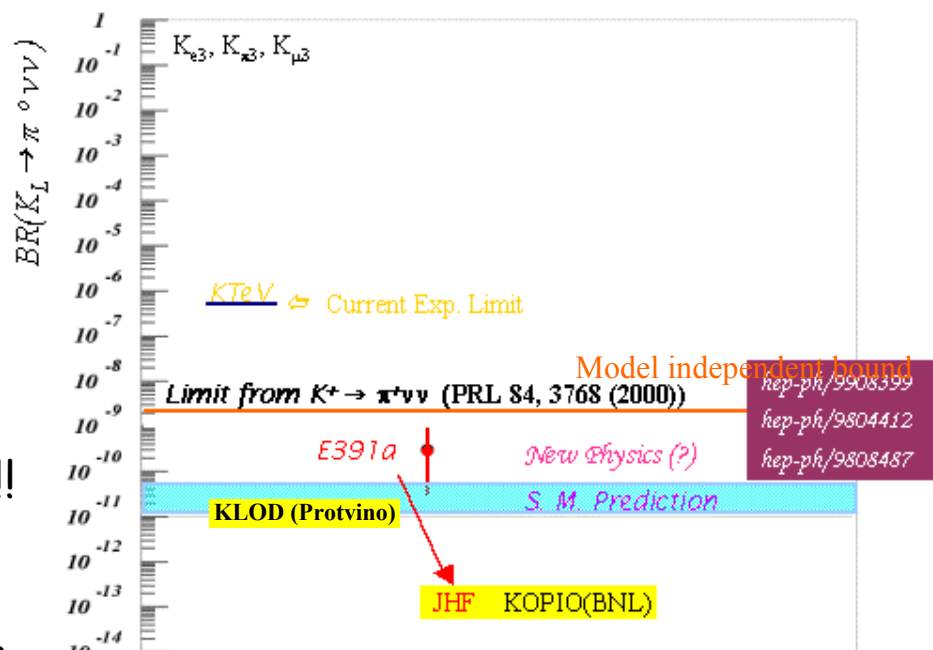
Will have few 10s of events

A new proton driver?

Assume: **4 MW** accelerator + stretcher ring

Unseparated ($\pi/K \sim 10$):
30 GeV (7.5 GeV K) 133μA (830 Tp/s: 20xAGS)
120 GeV (30 GeV K) 33μA (210 Tp/s: 7xMI)
400 GeV (100 GeV K) 10μA (63 Tp/s: 9xSPS)

RF-separated (p_K < 50 GeV, O(70%) purity):
50 GeV machine: maximum K⁺ yield at 12 GeV (0.48 K⁺/p/GeV/sr)

Ballpark numbers

O(few 10^{10}) K⁺/s
THz beams

Target efficiency	40%
Beam momentum	12 GeV/c ± 1%
Beam acceptance	75 μsr
Separator acceptance	50%
Duty cycle	30%
K⁺/year (10^7 s)	$2.6 \cdot 10^{15}$
K⁺ decays/year (in 30m)	$6 \cdot 10^{14}$

$3 \cdot 10^8$ K⁺/s
With 2% acceptance*eff:

1000 K⁺ $\rightarrow \pi\nu\nu$ events/year
(BR at 3%, ultimate)

with beam rate: 1.2 GHz

K Physics Summary

The information to be gained from rare K decays is not going to be exhausted with the arrival of LHC.

It's not going to be complete by then, either.

The focus is on precision rare decays (experiments starting now). These experiments are hard enough that they will require double-checks and complementary approaches.

The quality of the data is as important as the statistics: higher fluxes are crucial for control of backgrounds and systematics.

A high-intensity (MWs, tens of GeV, slow extracted) p machine would give an excellent (unique) opportunity to extract all the rich information available from K decays.

Hadron Physics

QCD and Strong Interactions

- **Strong interaction** studies will play a **crucial role**: QCD is ubiquitous in high-energy physics!

  Once new particles are discovered at LHC, it will be mandatory to explore parameters, mixing patterns, i.e., we need an **unprecedented ability** to interpret the **strong interaction** structure of **final states**

  Synergy: kaon system, heavy flavour, spectroscopy, pdf...

- Many **intellectual puzzles** still **open in QCD**
  - Confinement, chiral symmetry breaking, vacuum structure, hadron masses, origin of spin etc.

- **Parton distribution functions** (nucleon structure): a **grand project of QCD** over the last decades!

  Complex enterprise involving theoretical and experimental challenges

  Validation of QCD input parameters (PDF's, a_s) in view of the early stage of LHC

  The boundary between QCD for its own sake, and QCD as a servant for new physics is thin...QCD is anyway challenging!!

Possibilities for Hadron Physics at a High-Intensity Facility

Possibilities to provide many different beams and to address many different physics topics, advantages:
- ➢ FLEXIBILITY
- ➢ MODULARITY

- Antiproton beams
  ("low" energy, high intensity, good $\Delta p/p$)

- Hadron and photon beams (high energy high intensity)
  - ➢ hadroproduction with fixed target
  - ➢ photoproduction with fixed target

➢ Lepton beams

Light-State spectroscopy
Charmonium
Bottomium
Exotics (in a wide mass range)
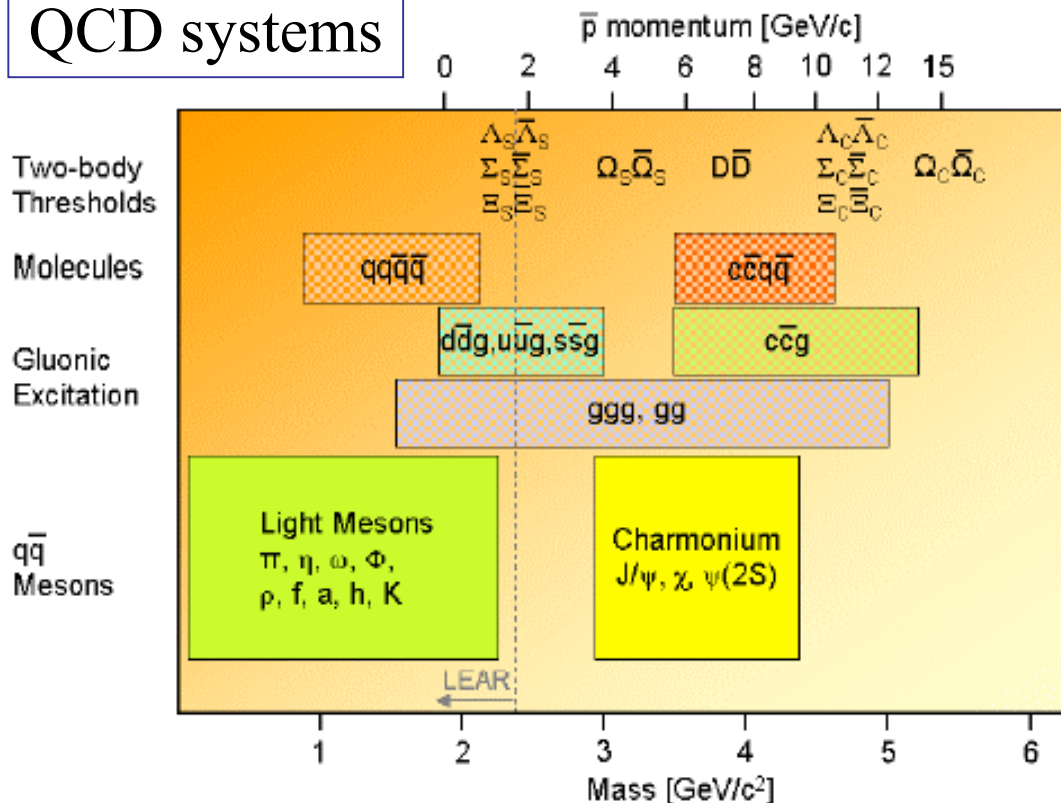Mixing & Rare decays
Heavy-Flavour Spectroscopy

ΔG, h_1, GPD's

Search for foreseen states, look for exotics (not yet established !!):

→ Light states

→ Heavy states

QCD systems

QCD
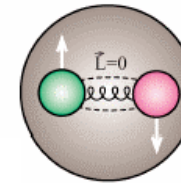
Meson ($q\bar{q}$)
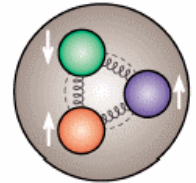
Baryon (qqq)

Glueball (gg)

Hybrid ($q\bar{q}g$)

$\bar{p}$ momentum [GeV/c]

Two-body Thresholds

Molecules

Gluonic Excitation

$q\bar{q}$ Mesons

$qq\bar{q}\bar{q}$

$c\bar{c}q\bar{q}$

$d\bar{d}g, u\bar{u}g, s\bar{s}g$

$c\bar{c}g$

ggg, gg

Light Mesons
$\pi, \eta, \omega, \Phi,$
ρ, f, a, h, K

Charmonium
$J/\psi, \chi, \psi(2S)$

LEAR

Mass [GeV/c^2]
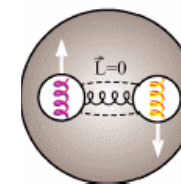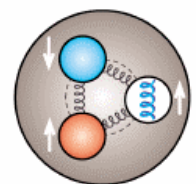
Many different experimental approaches.

17

Structure Evolution versus Statistics

100 events

1000 events
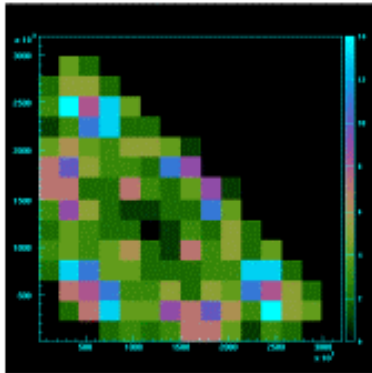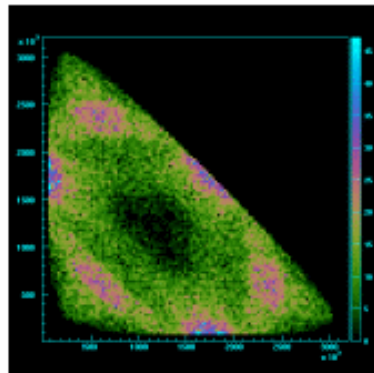
10,000 events

100,000 events

$p\bar{p} \to \pi^0\pi^0\pi^0$ Dalitz plot

$f_2(1565)$
$f_0(1500)$
$f_2(1270)$
$f_0(980)$

700000 events = 6×700000 entries

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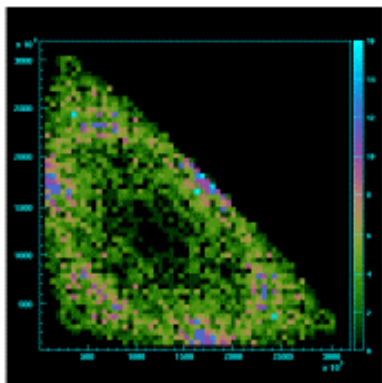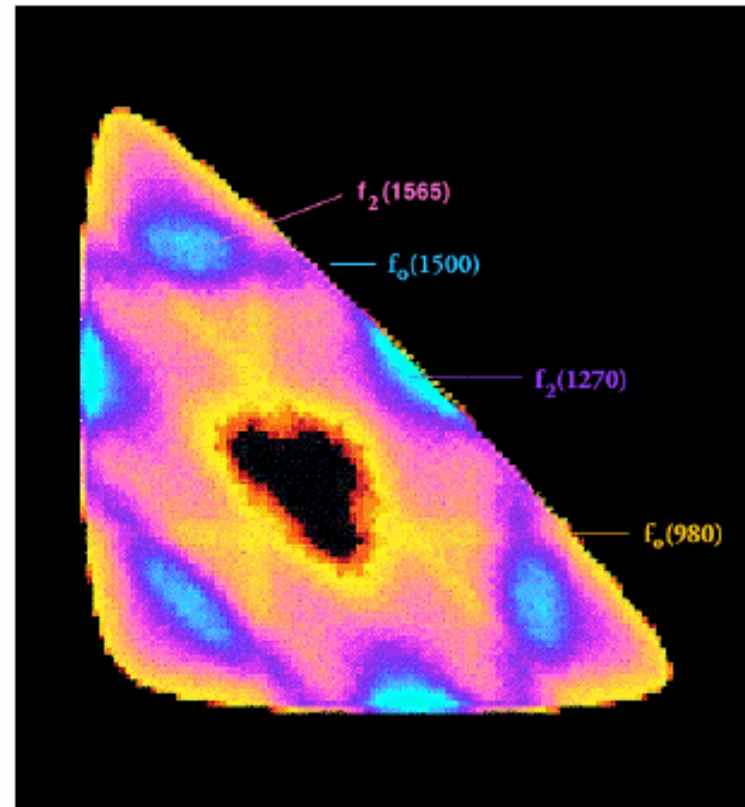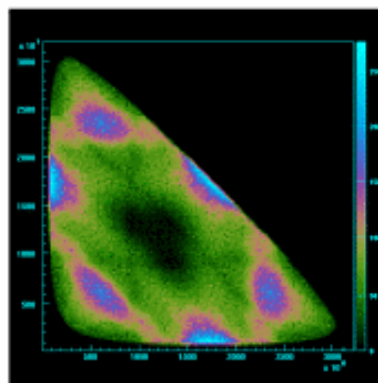
The Renaissance of Hadron Spectroscopy

- **Quarkonium**
  - η'_c (Belle, BaBar, CLEO)
  - X(3872) (Belle, CDF, D0, BaBar)
- **Narrow Charmed States**
  - D_{sJ} (BaBar, CLEO, Belle)
  - $D_{sJ}(2632) \rightarrow \eta D_s^+$ (Selex ?)
  - Ξ_{cc} (Selex ?)
- **Pentaquark candidates**
  - $\Theta^+(1540)$
  - $\Xi^{--}(1862)$
  - $\Theta_c^+(3100)$
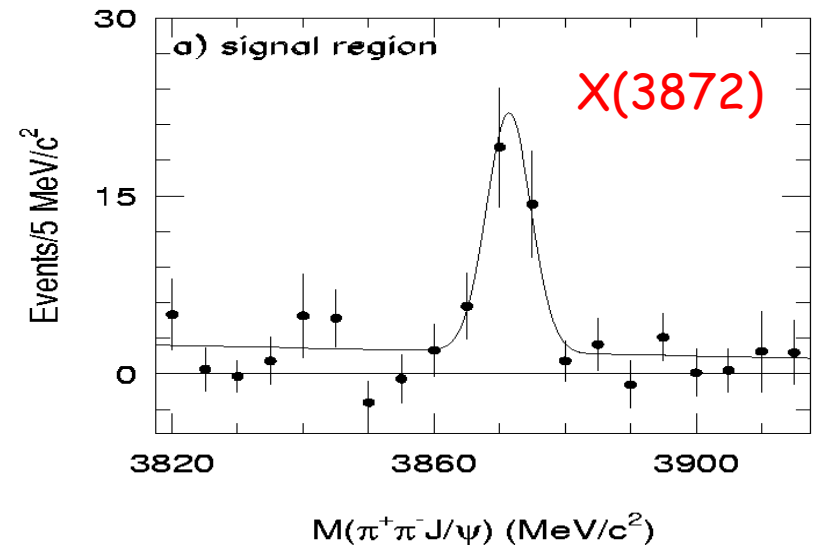
M = 3872.0 $\pm$ 0.6 $\pm$ 0.5 MeV
$\Gamma <$ 2.3 MeV (90 % C.L.)

- lepton number violating decays
- investigation of long-range effects and SM extension

Statistics is *conditio sine qua non!*

$$D^+, D_s^+ \to h^\pm \mu^\mp \mu^+$$

$$(h = \pi, K)$$

FOCUS improved results by a factor of 1.7 –14: approaching theoretical predictions for some of the modes but still far for the majority

CDF Br($D^0 \to \mu^+ \mu^-$) < 2.4 × 10^{-6} @ 90% C.L.
(65 pb^{-1} data)

Hera –B Br($D^0 \to \mu^+ \mu^-$) < 2 × 10^{-6} @ 90% C.L

CLEO-c sensitivity 10^{-6} CDF and D0 can trigger on dimuons $\to$ promising
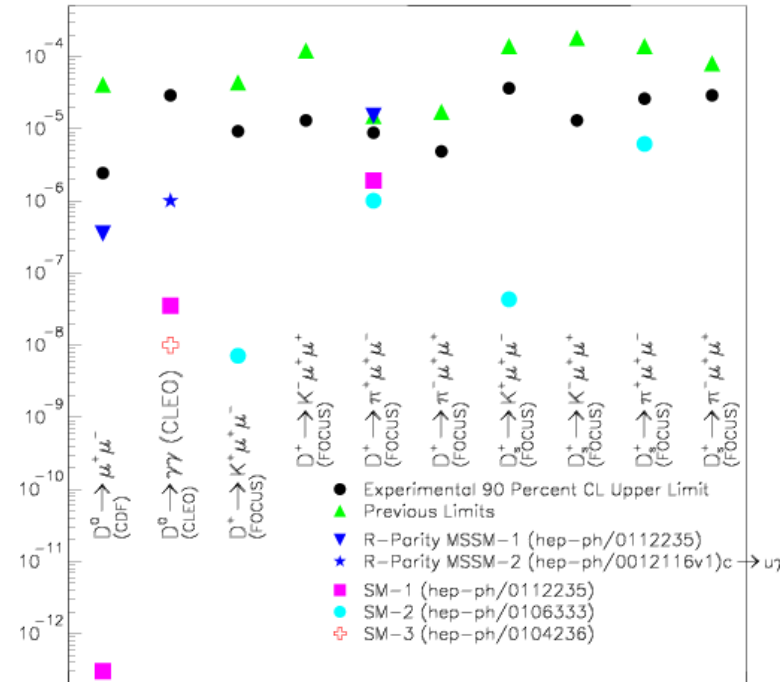
Hadron Physics with Antiproton Beams

"Low" Energy: $\sqrt{s}$ = 1÷10 GeV

High Intensity: $\mathcal{L} \approx 2 \times 10^{32}$ cm^{-2}s^{-1}

Excellent beam definition: $\delta p/p \leq 10^{-4}$

1. Light hadron spectroscopy and search for exotics.

2. Charmonium Spectroscopy.

    – Precise measurement of singlet states, scan region above open charm threshold, establish nature of X(3872) ...

3. Bottomonium Spectroscopy ?

    – Test QCD models, complement e$^+$e$^-$ data, unique way to make precision measurements on some states (η_b, χ_b, ...)

    – Scarce literature and data $\Rightarrow$ difficult to make numerical estimates

    – Experimentally challenging (rates, trigger, narrow widths ...)

    – Either 5Gev + 5 GeV $\bar{p}p$ collider or $\approx$50 GeV $\bar{p}$ on fixed target.

1. and 2. are a major part of the experimental program of the PANDA experiment at GSI, Darmstadt.

Hadro- and Photoproduction

Fixed-target program of Fermilab with about 100x statistics

Photoproduction: 100 x FOCUS, i.e. 10^8 reconstructed charm in a very clean environment

mixing–rare decays (cfr.CLEO-c)

Hadroproduction: 100 x SELEX

Help to confirm or not double-charm et al. (analysis issues)

SELEX:

$$\Xi_{cc}^+ \rightarrow \Lambda_c^+ K^- \pi^+ \qquad \sim 15 \qquad \Rightarrow \ (1500)$$

$$D_{sJ}^+(2632) \rightarrow D^0 K^+ \qquad \sim 15 \qquad \Rightarrow \ (1500)$$

$$D_{sJ}^+(2632) \rightarrow D_s^+ \eta \qquad \sim 45 \qquad \Rightarrow \ (4500)$$

what about background?!

Parton Distributions and Structure Functions

- Gluon helicity distribution. By the end of the decade expect $\Delta G/G \approx 0.1$ from open charm. Statistics limited. Possible competition from RHIC (γ+jet, jet+jet events, similar or smaller error, larger x range).

- Transversity.
  - Great evolution of theoretical landscape in recent years: many properties clarified.
  - Experimental effort is increasing: exploratory measurements being carried by HERMES, COMPASS and JLab.
  - Collins and Sivers asymmetries becoming more precise: first indications on h1 soon.

  Asymmetry is small, high intensity is a must: higher luminosity DIS

  and polarised $p\bar{p}$ collisions.

- Generalized parton distributions. Novel unified framework for the description of hadron structure. Accessible via Deeply Virtual Compton Scattering (DCVS) and Hard Exclusive Meson Production (HEMP).

  HERMES will devote last year of data taking.

Hadron Physics Summary

- **Strong interaction effects** have important (crucial) impact on **many different measurements** and **New Physics** searches
- Many short/medium term projects already planned
  - GSI-JLab-CLEO-c, BTeV/LHC-b
- Where will we be in 10 years from now?
- A vast program in the field of hadronic physics will be possible with a **diverse and flexible accelerator complex.**

Muons

Physics motivations: LFV

- Lepton flavor violation processes (LFV), like $\mu \to e\gamma$, $\mu \to eee$, $\mu \to e$ conversion, are negligibly small in the extended Standard Model (SM) with massive Dirac neutrinos (BR $\approx 10^{-50}$)

- Super-Symmetric extensions of the SM (SUSY-GUTs) with right handed neutrinos and see-saw mechanism may produce LFV processes at significant rates

μ-LFV decays are therefore a clean (no SM contaminated) indication of New Physics

and

they are accessible experimentally

Physics motivations : μ moments

1. **<u>Magnetic Dipole Moment</u>** (***g-2***) :

   ✓ measured and predicted with very high accuracy (10 ppb in electron; 0.5 ppm in muon), it represents the most precise test of QED ;

   ✓ most extensions of SM predict a contribution to ***g-2*** ;

   ✓ a 2.7 σ discrepancy between theory and experiment has raised a lot of interest (and publications) .

2. **<u>Electric Dipole Moment</u>** (μ**EDM**) :

   ✓ Like LFV processes, a positive measurement of μ Electric Dipole Moment (μEDM) would be a signal of physics beyond the SM

   Both experiments need a new high intensity muon source for the next generation of measurements

Connection between *LFV* and *μ-moments*

- In SUSY, g-2 and EDM probe the diagonal elements of the *slepton mixing matrix*, while the LFV decay $\mu \rightarrow e$ probes the off-diagonal terms
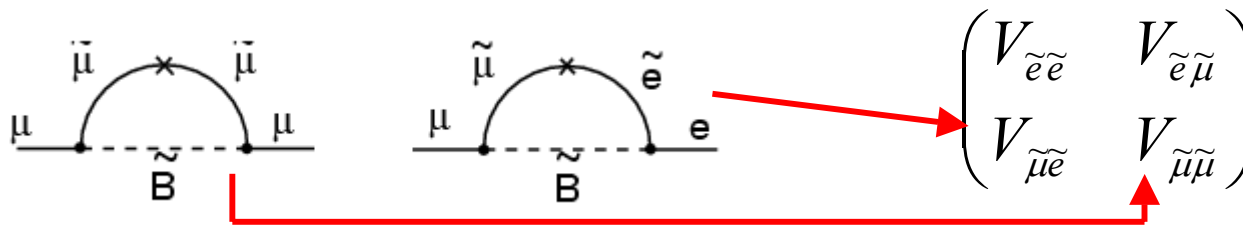
- In case SUSY particles are observed at LHC, measurements of the LFV decays and of the μ-moments will provide one of the cleanest measarements of *tanβ* and of the *new CP violating phase* .

The Anomalous Magnetic Moment : a_μ

QED
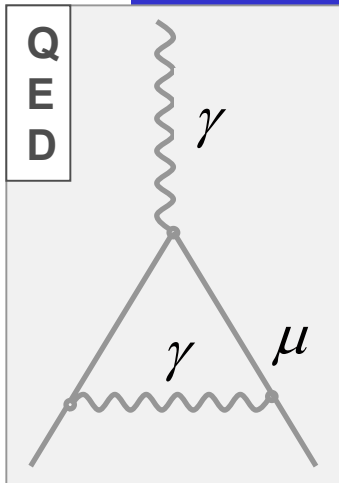
QED Prediction:

$$\Gamma_\mu = e\gamma_\mu + a_\ell \frac{ie}{2m}\sigma_{\mu\nu}q_\nu$$

Computed up to 4th order
[Kinoshita *et al*.]
(5th order estimated [Mohr, Taylor])

$$a_\ell = \frac{\alpha}{2\pi} = 0.001161\ldots$$

$$a_\mu^{\text{QED}} = \sum_{n=1} \left(\frac{\alpha}{\pi}\right)^n \approx \begin{pmatrix} 11614098.1 + 41321.8 \\ + 3014.2 + 38.1 + 0.6 \end{pmatrix} \times 10^{-10}$$

corrected feb 04

Schwinger 1948
(Nobel price 1965)

Kinoshita-Nio,
hep-ph/0402206

QED | **Hadronic** | **Weak** | **SUSY...** | **... or other new physics ?**
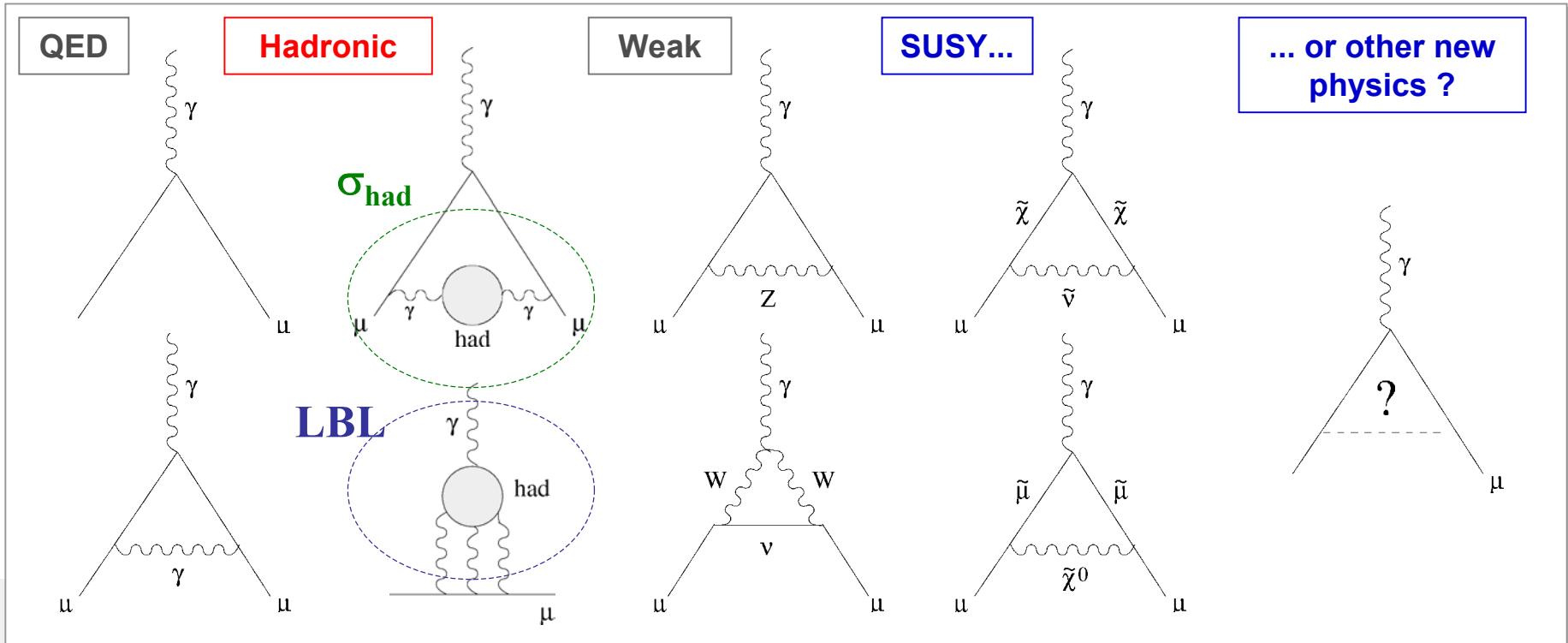
Including **CMD2** and **KLOE** e^+e^- results

Melnikov-Vainshtein, hep-ph/0312226

$$a_\mu^{SM}[e^+e^-] = (11\,659\,182.8 \pm 6.3_{had} \pm 3.5_{LBL} \pm 0.3_{QED+EW}) \times 10^{-10}$$

BNL E821 (2004) : $a_\mu^{exp} = (11\,659\,208.0 \pm 5.8)\,10^{-10}$

DEHZ 03 (e^+e^--based)
180.9 ± 8.0

DEHZ 03 (τ-based)
195.6 ± 6.8

HMNT 03 (e^+e^--based)
176.3 ± 7.4

J 03 (e^+e^--based)
179.4 ± 9.3
not yet published

TY 04 (e^+e^--based)
180.6 ± 5.9
not yet published

DEHZ 04 (e^+e^--based)
182.8 ± 7.2
preliminary

BNL-E821 04
208 ± 5.8

BNL-E821 04

$a_\mu - 11\,659\,000$ (10^{-10})
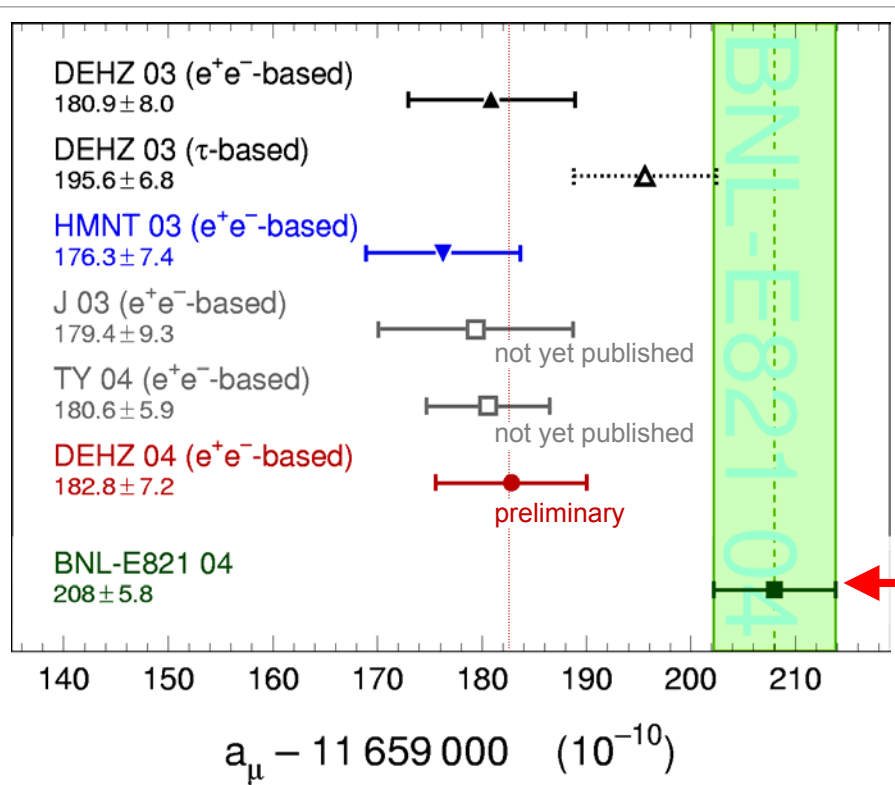
Observed Difference with Experiment:

$$a_\mu^{exp} - a_\mu^{SM} = (25.2 \pm 9.2) \times 10^{-10}$$

➡ 2.7 "standard deviations"
(using e^+e^- data only)

μ^+ and μ^- data combined together (CPT)

Possible new physics contribution…

- New physics contribution can affect a_μ through the muon coupling to new particles
- In particular SUSY can easily predict values which contribute to a_μ at the $\sim$1ppm level
- τ data can be affected differently than e$^+$e$^-$ data by this new physics
- In particular H$^-$ exchange is at the same scale as W$^-$ exchange, while m(H^0)>>m(ρ)
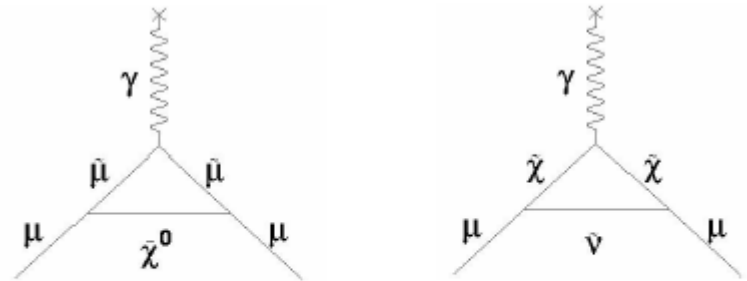
$$\Delta a_\mu^{SUSY} \approx 1.1\,\text{ppm} \times \left(\frac{100\,GeV}{\tilde{m}}\right)^2 \tan\beta$$

Marciano + others
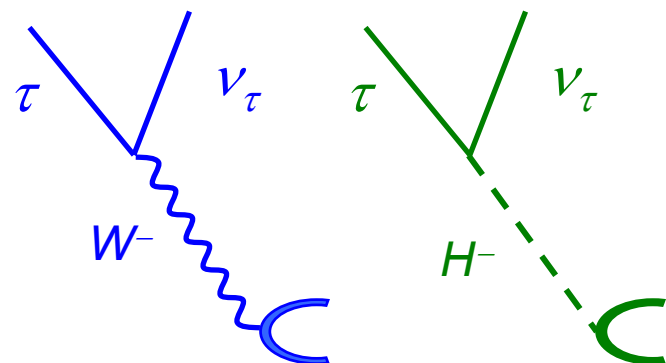
New proposal - statistics

- The new experiment aims to a precision of 0.1-0.05 ppm, which needs a factor of 25-100 more muons

- This can be achieved by increasing the …

  1. … number of primary protons on target $\rightarrow$ target must be redisigned
  2. … number of bunches
  3. … muon injection efficiency which, at E821, was 7%
  4. … running time (it was 7months with μ^- at BNL)

- The J-PARC proposal is mostly working on items 2 (go from 12 $\rightarrow$ 90 bunches) and 3

Electric Dipole Moment (EDM)

- The electromagnetic interaction Hamiltonian of a particle with both magnetic and electric dipole moment is:

$$H = -\vec{\mu} \cdot \vec{B} - \vec{d} \cdot \vec{E} \quad \text{where}$$

g-2 term

$$\begin{cases} \vec{d}_M \equiv \vec{\mu} = g \dfrac{e\hbar}{2mc} \vec{s} = \dfrac{g}{2} \mu_0 \vec{\sigma} \\[2mm] \vec{d}_E \equiv \vec{d} = \eta \dfrac{e\hbar}{2mc} \vec{s} = \dfrac{\eta}{2} \mu_0 \vec{\sigma} \end{cases}$$

- The existence of d_E, in SM, is suppressed because
  - d_E violates both P and T (and also CP in the CPT hyp.)
  - only one weak phase exists in CKM
- This is not the case for SUSY where many CP phases exist
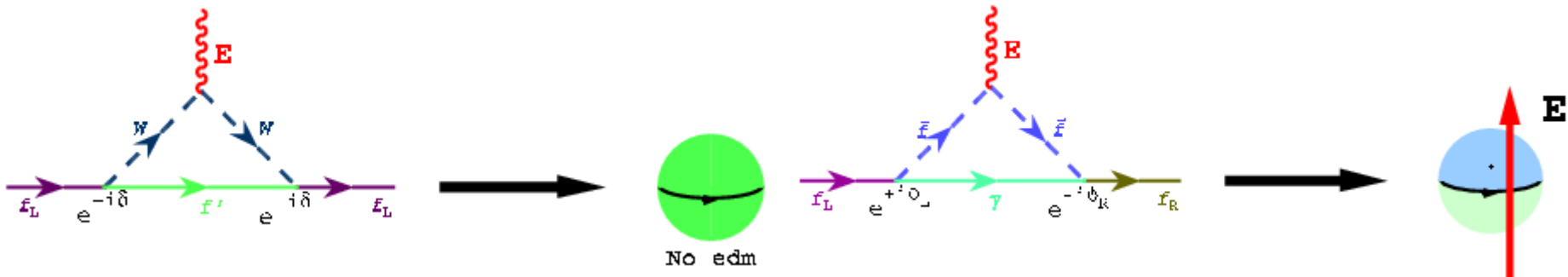
New approach to µEDM

- Muons in storage ring: combination of γ, **E**, **B** that <u>cancels out muon spin (g-2) precession</u> (electric field **E** must be radial and **E·β=B·β=0**) ; only µEDM precession left .

$$\vec{\omega}_a \propto a_\mu \vec{B} - K(\gamma)\vec{\beta} \times \vec{E} = \left(a_\mu B - K(\gamma)\beta E\right)\hat{z} \equiv 0$$ - precession due to a_μ

$$\vec{\omega}_{EDM} = \frac{e}{mc}\frac{\eta}{2}\left(\vec{E} + \vec{\beta} \times \vec{B}\right) \approx \eta \frac{e}{2mc}\beta B\hat{r}$$ - precession due to µEDM

NO out of plane precession

side view

(a)

(b)

Upper Detector

Lower Detector

Time [arb.]

Diego Bettor

34
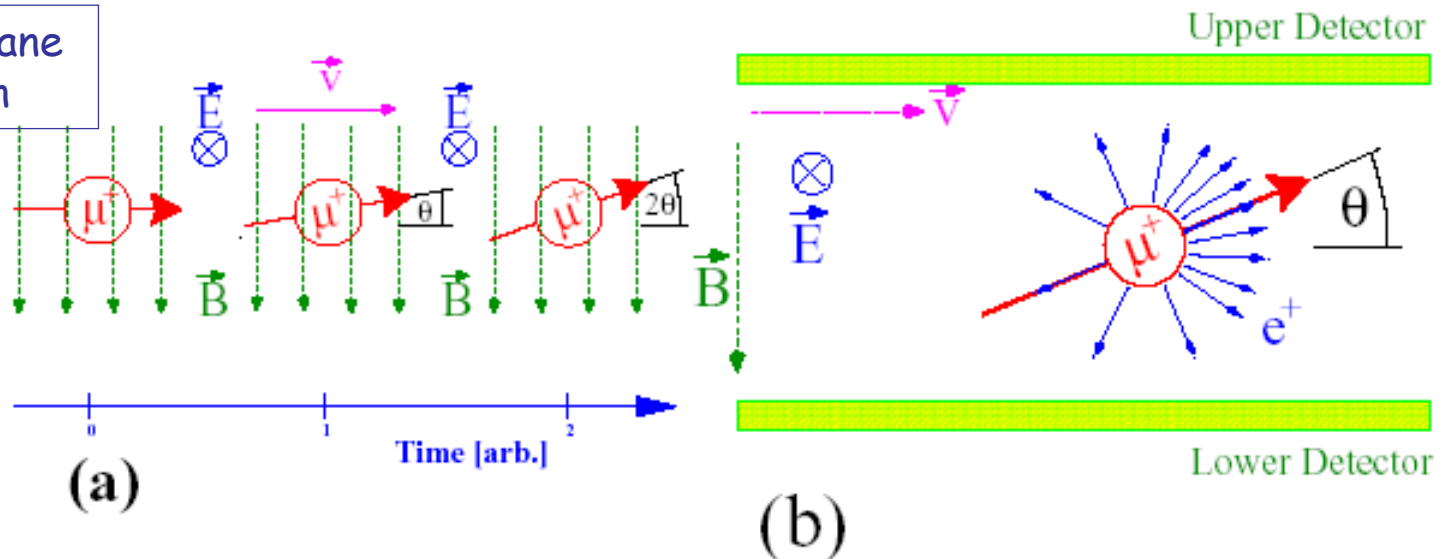
Present EDM Limits

Particle	Present EDM limit (e-cm)	SM value (e-cm)
n	6.3×10^{-26}	10^{-31}
e^-	$\sim 1.6 \times 10^{-27}$	10^{-38}
μ	$< 10^{-18}$ (CERN) $\sim 10^{-19}$ * (E821) *projected	10^{-35}
future μ exp	10^{-24} to 10^{-25}	

Summary on muons

- Both g-2 and μEDM are sensitive to new physics behind the corner
- Unique opportunity of studying phases of mixing matrix for SUSY particles
- Historically, limits on d_E have been strong tests for new physics models
- μ EDM would be the first tight limit on d_E from a second generation particle
- The experiments are hard but, in particular the μEDM, not impossible
- A large muon polarized flux of energy 3GeV (g-2) or 0.5GeV (μEDM) is required

Experiment	N_μ	p_μ(MeV)	$\Delta p_\mu/p_\mu(\%)$	sensitivity	$I_{off}/I_{on}, \delta T, \Delta T$
$\mu^+ \to e^+ e^- e^+$	10^{17}	< 30	< 10	BR=10^{-15}	DC beam
$\mu^+ \to e^+ \gamma$	10^{17}	< 30	< 10	BR=10^{-15}	DC beam
$\mu^- - e^-$ pulsed	10^{21}	< 80	< 5	BR=10^{-19}	$10^{-10}, < 100\text{ns}, > 1\mu s$
$\mu^- - e^-$ continuos	10^{20}	< 80	< 5	BR=10^{-19}	DC beam
μEDM	$10^{16}/P^2$	$300 - 500$	< 5	$10^{-24} e\, cm$	pulsed beam
$g - 2$	10^{16}	3100	< 2	< 0.1ppm	pulsed beam

Neutrino Physics

ν **Physics**

ν **oscillations are the most important discovery in hep of the last 15 years.**

They measure fundamental parameters of the standard model. Mixing angles, neutrino masses and the CP phase δ_{CP} are fundamental constants of the standard model.

They are a probe of the GUT scales . The smallness of neutrino masses is connected to the GUT scale through the see-saw mechanism.

They are directly linked to many fields in astrophysics and cosmology : baryogenesis, leptogenesis, galaxies formation, dynamic of supernovae explosion, power spectrum of energy anisotropies, etc.

They open the perspective of the measure of **leptonic CP violation.**

Neutrino physics case

- Solar + Atmospheric suggest a quasi-bi-maximal mixing matrix (**quite different from quark sector!**)

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

If $\theta_{13} \to 0$

the 3x3 matrix is just the product of two 2x2 matrices.

θ_{13} drives the $\nu_\mu \to \nu_e$ subleading transitions $\longrightarrow$

The necessary milestone for any subsequent search: CP search and mass hierarchy

Most of the parameters are waiting to be measured

δm^2_{12} ✔ SOLARS+KAMLAND
$\delta m^2_{12} = (7 +/- 1) \, 10^{-5} \, eV^2$

θ_{12} ✔ SOLARS+KAMLAND
$0.2 < \sin^2(\theta_{12}) < 0.5$

Addressed by a SuperBeam/Nufact experiment

δm^2_{23} ✔ ATMOSPHERICS
$\delta m^2_{23} = (2.0 +/- 0.4) \, 10^{-3} \, eV^2$

θ_{23} ✔ ATMOSPHERICS
$0.9 < \sin^2(\theta_{23}) < 1$

θ_{13} ⬭ CHOOZ LIMIT
$\theta_{13} < 14^0$

δ_{CP} ⬭ Mass hierarchy ⬭

$\Sigma \, m_\nu$ ⬭ BETA DECAY END POINT
$\Sigma \, m_\nu < 6.6 \, eV$

Dirac/Majorana ⬭

Outlook

WANF
CNGS

K2K
Miniboone

- "Traditional" Neutrino Beams

  ($\pi^{\pm}$, $\kappa^{\pm} \rightarrow \upsilon_{\mu}\ \upsilon_e$)

  – Narrow beams (NNB)

  – Wide Band (WNB)

- Super Beams

  – Off-Axis

- Neutrino –Factories (μ$^{\pm}$ -> $\upsilon_{\mu}\ \upsilon_e$)

- Beta Beams
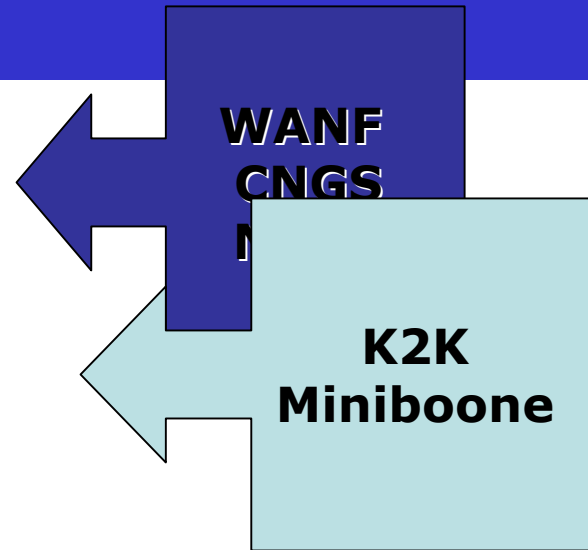
Timeline

At least 4 phases of Long Baseline experiments

2001

2010

2015

2020

year

10^{-1}

10^{-2}

10^{-3}

10^{-5}

$\sin^2(2\theta_{13})$

1) 2001-2010. K2K, Opera, Icarus, Minos.

Optimized to confirm the SuperK evidence of oscillation of atmospheric neutrinos through ν_μ disappearance or ν_τ appearance. They will have limited potential in measuring oscillation parameters. Not optimized for ν_e appearance (θ_{13} discovery).

2) 2009-2015. T2K (approved), Noνa, Double Chooz. Optimized to measure θ_{13} (Chooz $\times$ 20) through ν_e appearance or ν_e disappearance. Precision measure of the atmospheric parameters (1 % level). Tiny discovery potential for CP phase δ, even combining their results.

3) 2015 - 2025. SuperBeams and/or Beta Beams. Improved sensitivity on θ_{13} (Chooz $\times$ 200). They will have discovery potential for leptonic CP violation and mass hierarchy for $\theta_{13} \geq 1°$. In any case needed to remove any degeneracy from Nufact results (see P. Hernandez et al., hep-ph/0207080)

4) Ultimate facility: Neutrino Factories or high energy Beta Beams. Ultimate sensitivity on the CP phase δ, θ_{13}, mass hierarchy.

M. Mezzetto, "Beta Beams", Villars, September 24 2004.

2

Diego Bettoni INFN High-Intensity Studies 42

Summary on Neutrinos

- A huge work has been done in the last years to figure out which is the best facility for the neutrino sector, but so far no full convergence obtained yet.

- The measurement of θ_{13} is a very high priority.

- A high degree of flexibility is needed on the neutrino energy.

- It is necessary to evaluate carefully the costs vs physics priorities.

What Next ?

So far the INFN WG has studied mainly the physics issues. The next step is to address the experimental questions:

- Beam quality: energy, intensity, backgrounds, accuracies ...
- Detector issues: which are the conditions that will enable us to make the experiments ?

The idea is to carry out these studies in the next few months, identifying the issues which are common to other study groups (e.g. at Fermilab) and looking for synergies with these groups.
At this point our attention is not focussed on a particular machine in a particular lab, but any solution is considered.

Summary

A lot of exciting physics awaits us at the New High-Intensity Frontier:

- experiments with kaons and muons

  (CP violation, Lepton Flavor Violation, g-2 and muon EDM measurements)

- neutrino beams (superbeam, beta-beams and factories)

- hadron studies (spectroscopy, DIS, structure functions, antiprotons)

- nuclear physics

We look forward to a fruitful collaboration with Fermilab in studying the issues of common interest !